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NEW FORMS OF CONCRETIONS

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NEW FORMS OF CONCRETIONS

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SAND-CALCITE CONCRETIONS FROM SALTON, CALIFORNIA

A series of five sand-calcite concretions (Museum No. G, 1301) presented to the Museum by Mr. Herbert Brown of Yuma, Arizona, appear worthy of description. Regarding the conditions of the occurrence of these concretions little is known. Mr. Brown simply states that they were handed him by a commercial traveler as having been obtained by him at Salton, California. As there are extremely large sand dunes in the immediate vicinity of Salton, it is probable that the concretions were formed in these. Whether or not the form represented by the specimens at hand is a common or an unusual type in that locality is unknown. These concretions (Plate XIX) are formed of sand cemented by calcite, and are, therefore, of the type of the well known Fontainebleau and Saratoga Springs concretions, from which, however, they differ in several respects. The Salton concretions take the form of an irregularly botryoidal ball from which projects a stout, tapering stem in such wise that the object assumes the shape and proportions of an ancient mace. The change from head to stem is abrupt, much as if the stem were driven into a hole bored in the head, and there is even a slight annular depression in the latter where the stem enters. The botryoidal appearance of the head is due to a compound structure — each head being built up from a number of spheroidal concretions grown together. While there is but little flattening of the concretion as a whole, the subordinate spheroids are much flattened and also elongated in the line of the principal axis of the concretion. The specimens have a very rough surface from the presence in large numbers of rhombohedral points of arenaceous calcite crystals. These points suggest that these concretions, like those from Devil Hill, Wyoming, described by Barbour,* are aggregates of moderately large crystals. Lines of stratification (Plate XIX) intersect the specimens in such a direction as to indicate that the principal axes lie conformably with the strata in which they form.

* Bull. Geol. Soc. Amer., Vol. XII, p. 165.

The slight flattening of the complete individual as well as the greater flattening of the subordinate spheroids of the head is in the plane of bedding of the surrounding sand.

The specimens in the possession of the Museum weigh from 45 to 952 grams. The diameter of the ball lies between 30 and 70 millimeters, and that of the thickest part of the stem between 20 and 30 millimeters. The head of the concretion, therefore, varies much more in size than the stem. The stems, however, are very variable in length; the shortest is 55 and the longest 210 millimeters. Two of the specimens are compound, consisting respectively of two and three individuals grown together.

The specific gravity of the concretions is 2.69, and they are therefore a little denser than the average concretion of this character. Concretions of sand and calcite from Saratoga Springs in the Museum collections have a density of 2.62; those from Fontainebleau of 2.42. The sand-calcite concretions and crystals from Devil Hill, Wyoming, which have been studied by Barbour,* have a specific gravity, as determined by the present writer, of 2.64. According to Dana, the Fontainebleau crystals vary in specific gravity from 2.53 to 2.84.† The great variation in these figures is, however, not to be taken as indicating corresponding variations in the true density of the objects. They rather indicate differences in the methods employed by various experimenters and differences in the shape and size of the pores of different specimens. It is evident that the true specific gravity of a mixture of calcite and quartz cannot be less than 2.65, the specific gravity of the lighter constituent. The very great influence of the character of the pores and of the shape and size of permeable objects of the character of those under consideration are discussed in this paper, page 50. For the reasons there given, the specific gravities of the Salton, Fontainebleau, and Saratoga Springs specimens, determined at the Museum, are probably low, but it is believed only slightly so.

The carbonate cement of the Salton concretions is soluble rapidly and with brisk effervescence in cold dilute hydrochloric acid, and is therefore essentially calcite. The dissolved cement, however, yields noticeable quantities of iron to chemical tests.

The sand of the Salton concretions, when cleansed by cold dilute hydrochloric acid, is of a light gray color, subangular, and very fine. It all passes a 60 mesh sieve, 17% is retained upon an 80 mesh, 48% additional upon 100 mesh, and 35% passes through a sieve of 100

* Bull. Geol. Soc. Am., Vol. XII, p. 165.

† Dana: System of Mineralogy, p. 266.

meshes to the inch. It appears that the closeness with which the sand packs itself has some bearing upon the nature of the concretion. A sand of similar physical constitution was prepared from a mixture of glass sands by the use of sieves. This sand was packed into a glass cylinder and compacted by long tapping of the outside of the cylinder by a stout wooden rod. This sand, so compacted, enclosed between its grains 40% of voids which were calculated by the usual formula.*

Such a sand undisturbed in its natural bed may be assumed to compact itself in time somewhat more than it may be compacted by a few minutes' tapping in the laboratory. Such undisturbed sand beds, according to King and others,† contain 35% to 40% of pore space. Therefore if a sand-calcite concretion is composed of calcite filling voids previously existent between grains of sand, it will have by volume a composition of calcite 35–40%, silica 65–60%. The composition by weight will be approximately the same, as the specific gravities of the minerals differ but little. Such a composition has in fact been proved by the only two determinations of this character known to the author for similar concretions. These were carried out upon material from the two widely separated localities Devil Hill, Wyoming,‡ and Fontainebleau, France.§

A determination of the percentage of sand and calcite in the Salton concretions was made upon material broken from the stem. The fragments were treated with cold dilute hydrochloric acid and the insoluble sand weighed. The concretion was found to contain: sand, 29.17%; calcite, 70.83%. This corresponds to a composition by volume of about: calcite, 70%; sand, 30%. The above facts may be tabulated as follows:

COMPOSITION BY VOLUME OF SAND-CALCITE CONCRETIONS FROM THREE LOCALITIES:

	Sand, %	Calcite, %
Theory	65 – 60	35 – 40
Devil Hill	64	36
Fontainebleau	50 – 63	50 – 37
Salton	30	70

From this table it appears that in the Fontainebleau and Devil Hill concretions the calcite is little, if any, in excess of that required to fill the voids between the sand grains. The Salton concretions, on the other hand, have but half the sand and twice the calcite required for

* King: Physics of Agriculture, p. 115.
† Ibid.: p. 126; Warington: Physical Properties of Soil, p. 66.
‡ Barbour: Bull. Geol. Soc. Am., Vol. XII, p. 165.
§ Dana: System of Mineralogy, 6th ed., p. 266.

such a constitution. There are four hypotheses which may account for this excess of calcite: 1. The concretion may have formed in a partially opened crevice; 2. Part of the calcite may be fragmental; 3. Part of the sand may be impregnated with or replaced by calcite; 4. The calcite when crystallizing may have exerted pressure upon the sand grains and moved them apart.

The first hypothesis, a partially opened fissure, is practically negatived by many conditions and may be dismissed at once. Between the other three, microscopic study might discriminate. A slide was therefore prepared for this purpose, from a cross section of the stem of a concretion. The sand grains in this slide proved to be of the usual character of those sands which are derived from acid crystalline rocks. The great majority of the grains were quartz. Partially kaolinized feldspars were present in some quantity, also scattered fragments of biotite, muscovite, dark amphiboles, and a few grains of minerals not readily recognized. Such minerals as garnet, ilmenite, magnetite, etc., were completely absent. The grains varied from angular to well-rounded, but the greater portion were of a sub-angular character. With the exception of the slight kaolinization of the eldspars the minerals of the sand grains were wholly unaltered. The calcite proved to be wholly in the cement, and the cement contained no other mineral than calcite. No alteration of the calcite was observed, nor any calcite of fragmental origin, nor did any of it replace sand. The calcite was found to occupy more than half the area of the slide, the grains of sand seldom touched, but were separated by bands of calcite cement, which varied greatly in width. These calcite bands were frequently much wider than the diameter of the enclosed grains. It appears, therefore, that the calcite in crystallizing has exerted sufficient pressure to push apart the sand fragments, although no anomalous optical features were noted indicating strain in the cement. The cement was in the form of calcite crystals of cross sections comparable in magnitude with those of the sand grains. While many of them lay in parallel positions, sufficient data could not be secured from a study of the slide to determine whether or not the calcite is in the form of radiating crystals or of other regular or irregular aggregates.

The concretions in the Museum collections which possess a character most resembling the Salton forms in shape and appearance are from the two well-known localities: the Paris Basin, and Saratoga Springs, New York. The specimen from the Paris Basin which appears to possess the most in common with the Salton concretions

is a chain of four sand-calcite balls from Clermont. (Plate XX, Fig. 1.) This consists of four spheres between 140 and 160 millimeters in diameter united into a slightly curved chain 49 centimeters long. The spheres where they join interpenetrate for perhaps one-eighth to one-twentieth of their respective diameters. Each ball s nearly spherical with no marked flattening and is simple. The only complication of form is an abrupt change in diameter of the spheres giving each the external form of a laminated body from which the external shell has been half broken away. This is, however, a consequence of differing rate of growth for different sides of the sphere and is in no wise dependent upon internal structure. These deposits, which are associated with mineral springs, are doubtless more or less tufaceous in character.

The sand-calcite concretions of Saratoga Springs, New York, tend to form sheets by the coalescence of many ind.viduals and thus much of the material is better described as sandy calcareous tufa than as concretionary. The two specimens shown in Plate XXI illustrate this phase. These are respectively 15 x 40 and 17 x 20 centimeters in area and both are from 3 to 6 centimeters thick. Both specimens are fragments evidently broken from considerably larger sheets. The individual concretions from these sheets are forms modified from the sphere by agencies which have p oduced a flattening and elongation, so that the simplest form of common occurrence is a somewhat flattened ovoid or pear (Plate XXI, Fig. 1) with the same appearance of lamination which occurs upon the Paris Basin specimens. The larger number of those concretions which unite to form a sheet of tufa at Saratoga Springs are much more elongated than these pear shapes. Many of these more elongated forms so coalesce as to lose their identity and present merely a solid, wavy surface. When the individuality is not so completely lost, there arise, first, shapes resembling a long-necked gourd, then, as the elongation becomes greater, the flattening becomes greater also, the form becomes wavy in both the horizontal and vertical planes and deep, strong, longitudinal and occasionally transverse striations appear. Thus the elongated individuals forming these sheet-like bodies of concretion tend to become flat and more or less curved.

Besides the tufaceous sheets, separate individual concretions are common among the Saratoga Springs material. These show little or no flattening and sometimes but little departure of any kind from a spherical form. They are frequently heavily striated in a meridional direction by deep grooves which come together at two

poles. When compounded, they assume grotesque and imitative forms. The nearest approach to the Salton forms is a double concretion from Saratoga Springs (Plate XX, Fig. 2). This consists of two cones with hemispherical bases. They are similar in form but differ in size. The apex of the smaller is united with the base of the larger. The length of the specimen is 38 centimeters and its greatest diameter 8 centimeters. This may be considered as two independent concretions which have grown together, and the larger cone alone may be compared with the California specimens. This larger cone is as smooth on the surface as the sand which enters into its composition will permit. It is slightly curved. There is the usual fold-like longitudinal swelling where it has grown faster in one direction than another. The cone tapers gradually with no abrupt change of curve from the widest portion to the apex. The relation between the specimens from Salton and those from Saratoga Springs and the Paris Basin are best brought out in tabular form:

COMPARISON BETWEEN SAND-CALCITE CONCRETIONS FROM THREE LOCALITIES:

	Salton.	Saratoga and the Paris Basin.
Surface:	Roughened with rhombohedral points. Never striated.	Smooth. Often striated.
Spherical forms:	Compound. Oblate.	Simple. Prolate or ovoid. Pseudo-concentric.
Elongated forms.	Circular section. Straight.	Flattened section. Curved or wavy.
Junction of spherical to elongated form.	Abrupt.	Always gradual.

Lack of data prevents discussion of the nature or origin of these concretions from Salton, California. There is, however, one suggestion which is called forth by the shape of these objects when they are compared with some hitherto unrecorded forms of concretions of an entirely different character. The stem of any one of these California specimens is very like a stalactite depending from the head.

In certain sand dunes, notably in the "Hoosier Slide" of Michigan City, Indiana, flat sheet-like bodies of limonite concretion form in certain strata of the sand. When these are dug out, numerous small stalactites of limonite are found depending from their lower surfaces.

These stalactites are, however, too friable to be preserved. These limonite concretions form by deposition from a sheet of ferriferous water which flows during wet weather along a more permeable layer of dune sand or upon the surface of a comparatively close-packed and impervious stratum. It is evident that this comparatively impermeable layer is able to form in wet weather some fashion of floor for the stream of iron-bearing waters. This floor is, however, but imperfect and very leaky, so that the limonite stalactites have ample opportunity to form where the water drips through. It is very possible that in the case of these sand-calcite concretions some similar structure of the dunes near Salton has permitted a similar stalactite to form at the base of such concretions as were favorably placed.

SAND-BARITE CRYSTALS FROM OKLAHOMA

These specimens (Museum No. G. 1285, Plate XXII) were collected by Prof. Charles N. Gould of the University of Oklahoma and presented by him to this Museum. They are found, according to Prof. Gould, along the outcrop of a belt of red sandstone in Eastern Oklahoma. This belt is about ten miles wide and extends for a distance of fifty or seventy-five miles through several counties, particularly Cleveland, Oklahoma and Lincoln counties. Prof. Gould referred to the specimens in conversation as "sand crystals." Dr. Otto Kuntze in a similar way calls them "barite pseudomorphs." In the catalogue of a Western mineral dealer they are listed as identical with certain "silico-barite concretions" collected in Kansas. An Eastern dealer calls them "gypsum pseudomorphs." It may be inferred from these differing appellations that there is more than a little uncertainty regarding the nature of these objects.

Twelve specimens which came into the posssesion of the Museum at the close of the St. Louis Exposition vary from 2½ to 7 centimeters in diameter and from 10½ to 364 grams in weight. They assume the form of rosettes which are composed of aggrègates of tabular crystals resembling lamellar-nodular aggregates of gypsum, barite and other minerals. The facės of the plates are, however, somewhat rounded on the edges as if eroded and hence not sufficiently definite in form to permit of exact measurements or determination. According to Prof. Gould they vary in size from that of a pea to a diameter of five inches. They are found both enclosed in the sandstone and weathered out.

A series of 32 specimens received later confirms the characters of the earlier lot. They include a number of globular specimens which, however, have the same structure as the rosette forms, from which they differ in the number and dimensions of the component plates. That is, the globular forms are merely thick rosettes. One specimen consists of a group of many nearly globular forms enclosed in the weathered matrix which assumes the form of a red sand. This sand appears to be the residue left from solution of the limonite cement of a ferruginous sandstone.

The rosette appears upon both sides of an approximately octagonal plate which may be designated the basal plate of the aggregate. This is penetrated obliquely by a variable number of similar plates which appear to intersect at the centre of the aggregate and project on both surfaces. These plates make angles of approximately 30° with the bases. While these plates appear as if passing through the basal plate and any important one appearing on one side may be readily discovered on the other, yet the two rosettes are never exactly alike. One is always more complex than the other and formed of smaller plates. These plates generally, but not always, lie in a confusedly whorled position. They are not simple but frequently consist of two plates inclined to each other at angles of approximately 30° and intersecting some in the vertical and some in the horizontal plane. By repetition of this compounding of plates, always at angles of approximately 30° so far as the roughness of the material will allow determination, the apparently irregular orientation of the leaves of the rosettes may be accounted for. By a greater degree of this compounding also is the greater complexity of one face over the other produced. The specimens, examined detail by detail, are decidedly unsymmetrical, yet when the broader features only are considered, symmetry of a high order is present. The rosettes on either side of the basal plate while not identical in detail are so in mass, and proportioned so that the aggregates are symmetrical with respect to the plane of the basal plate, as well as to a central axis at right angles to this plane. There is also a tendency in some of the specimens towards an axis of hexagonal symmetry in the plane of the basal plate. The secondary plates appear to so twist as to all intersect along this axis.

The position of those portions of the plates which lie buried in the body of the specimen may be followed by the cleavages upon the fractured surfaces. From an examination of these cleavages it becomes evident that the plates do not really intersect or interpene-

trate. While the projecting and visible portions are plane, that portion of each plate which is buried in the mass of the aggregate is invariably curved and frequently very strongly so. Hence a plate that appears from the general form to pass through the basal plate frequently curves sharply into almost a U shape, with both sides projecting upon the same side of the specimen while another similar U-shaped plate lies symmetrically in the opposite rosette. Other plates upon approaching plates that they appear to penetrate, terminate there in a wedge, and a similar form symmetrically placed gives the appearance of a penetration that does not exist. In some instances the aggregations are double. One specimen consists of two rosettes in parallel position which have simply touched each other and adhered. Another consists of two individuals at right angles which have grown together giving the effect of a more or less spiral, elongated form.

The exterior of the specimens is of dark reddish-brown color, while the interior is of a pale pink closely resembling the color of some pink orthoclases. When broken a good cleavage developes in the form of a minute step structure of very brilliant facets in parallel position with pronounced pearly lustre. When the fracture is examined under the magnifying glass the cleavage is obscured by a granular structure which is exactly that of a broken face of sand stone. The specimen is obviously composed of grains of sand cemented by a mineral which possesses an eminent cleavage in at least two directions. The average specific gravity of the nodules is 3.348. The individuals do not vary greatly in density from this mean. The color is discharged upon intense ignition but returns upon cooling. The color after ignition however, is fainter than before.

A slide was prepared and studied under the microscope. This appeared as an aggregate of angular quartz fragments of several sizes enclosed by a cementing mineral which completely filled all voids or interspaces between the quartz. The quartz grains were surrounded by a thin red coating which resolved under high power into groups of brownish-red isotropic spherules and ellipsoids upon the surface and in the fractures of the quartz grains. The granular fragmental material was almost wholly quartz. One small, isotropic fragment of yellow color, high refraction and no visible cleavage, presumably garnet and one good sized fragment of clouded orthoclase appeared.

The cement was an anisotropic mineral of two cleavages, one better defined than the other, which lie at an angle of 90°. There was a third cleavage parallel or nearly so, with the plane of the slide

which did not appear as cracks upon the surface of the section. The extinction was parallel to the principal cleavage, which lies in the plane of the axis of least elasticity. The index of refraction of this mineral was greater than that of the quartz. The cement throughout the entire slide was part of one crystal with the growth of which the sand grains present had not interfered. This was indicated by the cleavage, which was everywhere parallel with itself, and by the interference color which was the same hroughout the slide. The high specific gravity of the specimen and the presence of much barium sulphate, taken with the features shown in the slide indicate that this cement is barite. In this slide it was evidently cut parallel to *m* and showed the usual cleavage parallel to *c* and one set parallel to *m*.

An analysis of the specimens made in the Museum laboratories by the author gives the following result:

SiO_2	36.99
BaO	35.76
SO_3	19.20
Fe_2O_3	0.82
Al_2O_3	5.36
CaO	0.51
MgO	0.03
H_2O*	0.27
Organic†	0.32
	99.26

This corresponds with a mineral composition (disregarding the silica required for the aluminous minerals) of:

Barite	54.42
Quartz	36.99
Miscellaneous	8.59
	100.00

From the analysis it would appear that some aluminous mineral is present bu; the slides fail to disclose such in quantities required to satisfy the analysis. Inasmuch as barite frequently contains similar elements as mpurities even when well crystallized, it appears best to provisionally include the minor elements in the barite for an approximate determination of mineral composition. The mineral composition thus becomes:

Barite	63
Quartz	37
	100

This corresponds to a specific gravity of 3.77 against 3.380

* From air-dried specimen, by Penfield's method.

† Loss on ignition less water.

actually found for the individual from which the material for the analysis was taken. This discrepancy would be too great were it not for the fact, elsewhere discussed in these papers, that the specific gravity determined for these mineral aggregates is commonly too low owing to air trapped in pores, cracks, etc., which cannot be wholly removed by boiling or by the air pump. If, however, we assume that all the bases except the barite are in the form of silicates which have a density equal to quartz, the calculated density 3.62 is but slightly lower than that before obtained.

By the method described on page 27, the space occupied by the quartz and barite may be calculated. The calculation so made shows that the quartz occupies 50% of the volume of the concretion and the barite 50%. As sand naturally packed generally ncludes about 40% of voids between the grains, it appears as if the barite had crystallized between the grains of sand and very slightly pushed them apart by pressure when growing. Indeed there are in the slide examined, here and there a few evidences of slight pressure upon the cement in the shape of a rise in the order of interference color combined with a wavy extinction. These spots however are very few and very small.

These specimens are, therefore, not concretions in the narrow sense of the term, but crystal aggregates of barite with sand present as a mechanically held impurity. They bear the same relation to the known occurrences of sandstone with barite cement that the sand-calcite crystals of Fontainebleau and Devil Hill do to the sandstones with calcareous cement.

LIMONITE-SAND CONCRETIONS, SPRING LAKE, MICHIGAN

These concretions (Museum No. G. 1223, Plate XXIII) were collected at Spring Lake, Michigan, by the author. They occur on the tops of dunes where the sand has been overgrown with grasses and shrubs. In places the vegetation has disappeared and the sand has again begun to move. Thus there are formed shallow pits where the surface has been removed to depths of from an inch or two to five or six feet below the sod. These concretions lie on the surface of these pits in the loose sand. From the shallowness of some of these pits, it is evident that many of the concretions must be formed within a few inches of the original sodded surface of the dune. Inasmuch as in the deeper pits the supply of concretions is not perceptibly greater than in the shallowest of all, it appears that few, if any, of the concre-

tions originate at any considerable depth below the surface. The concretions are irregular, lumpy forms without approach to any regularity or symmetry beyond the fact that the majority of them are more or less flattened and many have one flat side. They are occasionally penetrated by minute cylindrical holes up to 2 mm. in diameter such as would be the case if they had been penetrated by rootlets. They are of reddish-brown limonite color rarely approaching a hematite-red in places. They are but slightly consolidated and may be readily reduced to their constituent sand grains by pressure of the fingers. They do not commonly exceed 5 centimeters in any dimension. In composition they are dune sand cemented by a small proportion of limonite which does not fill the voids between the grains. The limonite is merely a coating on the sand grains. Whenever the grains touch their coatings coalesce, thus cementing the sands into a concretion. There is no evidence of any nucleus in any of the specimens examined nor is there any determinable concentric structure.

There is no mystery about the origin of these forms beyond the determination of which of three or four common agents has been the predominant precipitant of the cement. The sand of the dunes in which they were found is, like nearly all dune and beach sand, of a yellowish-brown color. This color is due to a thin coating of limonite. Where the dunes have not been fixed by vegetation, this color is not noticeably lighter at the surface than it is in depth. Where a dune is fixed by vegetation a light sod often forms over the surface. Under this sod the sand is much lighter in color for a depth of a few inches than it is at greater depth. Hence it is to be inferred that the organic compounds derived from the vegetation have, as is customary, dissolved the iron oxides from that sand which lies immediately under the sod. From organic compounds containing iron dissolved in the so-called humus acids, the metal is rapidly precipitated by any one of several agents, the more common of which are spontaneous changes in the organic solvent, bacterial action, oxidation and hydrolysis. The hydrated ferric oxide precipitated is deposited by preference as a film upon the surface of the sand grains and by spontaneous dehydration forms the limonite cement.

As he precipitation has fol'owed so immediately on solution as to produce concretions within a few inches of the surface it is probable that the precipitating agent is either air in the pores between the sand grains, iron-secreting bacteria, or more probably a hydrolization of iron compounds of weak organic acids consequent upon

large dilution of the solvent when removed from the immediate vicinity of the decaying root or leaf which is the ource of its supply.

Such small limonite-sand concretions forming near the surface of semi-fixed dunes are, therefore, due to an action of vegetation upon the limonite coatings of the sand grains of the dune, an origin not unlike that of the bog and pond limonites.

LIMONITE GEODES, MUSCOGEE, INDIAN TERRITORY

A series of limonite geodes (Museum No. G. 1308) of unusual character was presented to the Museum by General G. Murray Guion. According to General Guion the geodes are found in clay in the bottom of a "draw" or ravine at Muscogee, Indian Territory. These specimens are composed essentially of limonite with turgite and consist of a crust, a core and a central cavity. They are of the irregular discoid form with smooth exterior which characterizes a common type of siderite nodule. They are of moderate size. A typical specimen (Plate XXIV, Fig. 4) weighs 270 grams, has a diameter which varies from 10 to 12 centimeters and a thickness of 4 centimeters. When the specimen lies flat its horizontal projection is a decidedly irregular oval. All vertical projections and sections are ovals, slightly irregular but symmetrical with respect to the major diameter. Some specimens possess th cker and some thinner forms than this. The surface is smooth except for such roughness as is due to scaling of the lamellar crust. The color is light gray with dark brown stains. Some specimens are coated with a firmly adherent yellow ochreous clay in which they appear to have been imbedded, while many specimens are perfectly free from this coating. The specimen shown in the illustration is enclosed in a light-colored laminated crust. Inside the crust and sharply separated therefrom, is the main portion of the geode, a hard, red and yellow, concentrically banded, agate-like mass of limonite and turgite. The center is occupied by a small cavity which varies in shape and size in different specimens, and suggests in outlines the central cavity often found in agates.

The shell is from 3 to 7 millimeters in thickness. Its external color is gray to brown; fractured surfaces are ight gray with dark brown and limonite yellow areas. The outer portion of the crust is almost universally light gray, while the inner parts contain more of the darker areas.

The crust is strongly laminated, especially in the outer portions. The individual laminae, which are somewhat under a millimeter in

thickness, are very brittle and break readily in some instances into little, straight-sided rhombs which are not uniform in shape or size. The hardness of this crust is about that of calcite. In appearance the material of this crust resembles a siderite partially altered to limonite. A chemical test, however, proves it to be limonite mixed with clay and a very little calcite.

Inside this shell is the core, which comprises the principal mass of the specimen. This core readily separates from the shell when the geode is broken. It consists of hard red turgite, banded concentrically with limonite. (Plate XXIV, Fig. 3.) The red portion forms by far the larger part of the core. The hardness of the core like that of the crust is about that of calcite. This core is of a smooth, earthy texture. It rubs off sufficiently to soil paper readily. The agate-like banding is disposed somewhat symmetricallywith reference to the centre and the outside. A section of the core presents an annular form. The centre of this ring is occupied by a broad red band, outside and inside of which are thin, alternating bands of yellow and red, while the broad central red band is itself made up of a multitude of minute, almost invisible bands of two shades of red.

The central cavity is small in proportion to the size of the geode. One specimen which has been sawn through the centre presents a section of an average diameter of 6 centimeters. In this specimen the section of the cavity occupies a space of 15 by 5 millimeters. The section of the opening has the form of an irregular pentagon with sharp angles suggesting a crystal outline which is common among agates. The cavity in this instance has a dark brown, slightly iridescent coating of botryoidal limonite with two small areas of colorless, transparent opal also botryoidal A thinner specimen of about 5 by 25 millimeters section when sawn through the centre reveals the central cavity reduced to a mere slit of 2 by 10 millimeters. This cavity is in the red turgite and has no limonite coating. It has, however, a partial coating of an opaque white powder, the nature of which has not been determined.

Composed of quartz, these specimens would be typical agates. Therefore it is most probable that they were formed in the same way as agates by the deposition of oxides of iron instead of silica. As in the case of agates slight changes in the conditions of deposition cause changes in the color and porosity of silica deposited, so in this instance slight changes in the surroundings or in the mother liquor have caused alternate depositions of more and less hydrated oxides of iron. Further discussion of the origin and nature of these objects would

appear unprofitable until their occurrence has been investigated in the field.

LIMONITE GEODES FROM THE OHIO RIVER

A series of four hollow limonite objects (Museum No. G. 1307) of rhombohedral form which were presented to the Museum by Dr. W. S. Gilmore prove to be limonite geodes. (Plate XXIV, Figs 1 and 2.) They are described as occurring in large numbers in clay upon the banks of the Ohio River about 30 miles from Owensboro, Ky.

They are small, weighing from 28 to 64 grams. They are all of approximately the same thickness, 25 millimeters, the same width, 25 millimeters and vary in length from 26 to 60 millimeters. With the exception of one imperfect specimen they are bounded by plane faces and are in form typical joint rhombohedrons formed between bedding planes and three systems of parallel and intersecting joints perpendicular to the bedding. Two systems of the joints are practically perpendicular to each other. The third system intersects the others at angles varying from 40° to 60°. In all the specimens two parallel surfaces which differ in color from, and are more earthy in texture and rougher than the others, are identified as bedding planes.

The surface of the geodes is yellow on the bedding planes and dull red to brown on the joint faces. Fractured surfaces are dull brown and smooth, with a yellow streak at the inside edge. The specimens are hollow, with thicker walls along the bedding planes than along the joint surfaces.

In one specimen (Plate XXIV, Fig. 2) the walls of the geode in contact with the bedding planes have a thickness of 5 to 7 millimeters, while the walls in contact with joint planes have a thickness of only 1 to 2 millimeters. This specimen happens to be double, the half-specimen or individual to which the above measurements refer having a breadth and thickness respectively of 24 and 16 millimeters The interior hollows of the unbroken geodes are filled with a tough, yellow, ochreous clay, reticulated on the surface with drying cracks.

It is very ev dent from the form and structure of these objects that they are formed at the intersection of joints and bedding planes. They do not represent actual open spaces, but rather are blocks of clay enclosed by these fractures and modified by the introduction of limonite from the exterior by ferruginous waters. These waters do not appear to have deposited their iron in the joint openings them-

selves to any considerable extent, as in this case there would be instead of individual geodes, a cellular honeycomb structure of limonite enclosing clay in its meshes.

The limonite has been deposited principally, perhaps wholly, where the ferruginous waters have soaked into the clay as coatings upon the individual clay particles. Not filling the joint fractures, the limonite coatings of adjacent specimens do not commonly adhere. When they do adhere, compound or twin geodes are formed. The source of the iron cannot be determined, as practically nothing is known of the mode of occurrence of these objects. Except for the outer form, these objects simulate closely those concretions that are assumed to originate in the decomposition of a pyrite nodule and the deposition of the resultant oxide of iron around it. It is a question if many of the hollow iron concretions may not be geodes of this nature, although it is certain that not all are. If the deposition of iron oxide continued long enough, such a deposit would become one of argillaceous limonite.

NODULES FROM THE CHALLENGER AND ARGUS BANKS IN THE ATLANTIC OCEAN

While engaged in collecting fish for this Museum, Dr. Tarleton H. Bean, on the 12th of October, 1905, dredged from the Challenger Bank sixty-four calcareous nodules. The following day he dredged from the Argus Bank twenty-eight similar nodules. These specimens, now a part of the Museum collections (Museum Nos. G. 1323–30), are sufficiently problematic in character to be worthy of some study, especially as, if of a certain character, they would have an important bearing upon geological and geographical problems of great interest.

The Challenger Bank, whence the larger number of specimens were secured, is a shoal of from five to ten miles diameter, rising abruptly from the depths of the sea to within twenty-four to thirty fathoms from the surface. The Bank lies thirteen miles southwest of Gibbs Lighthouse, Bermuda, and is separated from the Bermuda Bank by a space of three and one half miles of deep sea, where soundings exceeding 1,000 fathoms have been taken. The Argus Bank is a shoal of similar dimensions and depth of water about twelve miles southwest of the Challenger Bank, from which it is separated by a trough of five hundred fathoms depth. There is no shallow water connection between these two banks, nor with any other shoals or land.

It was the opinion of James D. Dana* that these two banks were, in comparatively recent historical times, islands, which were even mapped as "The False Bermudas." Early accounts of these banks described them as "rocky ledges."† The ship Challenger visited the bank of that name upon the 23d of April, 1873. Upon its map of the region‡ the character of the bank is given as coral. Sir C. Wyville Thompson,§ who was with the Challenger expedition, says: "The bank, which seems to be about five miles across, consists mainly of large rounded pebbles of the substance of the Bermuda serpuline reef. There is an abundant growth all over the pebbles of the pretty little branching corals, *Madracis asperula* and *M. hellana*." He mentions also that starfish and other animals were brought up in the dredge. Mr. Bean, dredging in 28 fathoms, found that the bottom was covered with the nodules under consideration, which are doubtless identical with Sir Wyville Thompson's pebbles. The nodules were, however, imbedded in calcareous ooze, and although covered by living forms, the branching skeletons, which may well correspond with *Madracis*, appear from inspection of the dried specimens to have been dead sufficiently long to become encrusted with bryozoa and nullipora.

If these nodules are rolled fragments of serpuline limestone, both the existence within a few hundred years of the False Bermuda's and their extremely rapid subsidence is as good as proven. The three and one half miles of deep sea which separate the banks from the nearest reefs offer an insuperable obstacle to the transportation of pebbles in such large numbers. Such nodules of fragmental origin also could not form *in situ* under present conditions, for wave action at depths of twenty-four to thirty fathoms is either very weak or entirely lacking. The current of three knots has not sufficient power to round boulders of such size. If, however, they are accretions, they have little or no apparent bearing upon these questions, and the interest in them arises from other sources.

The nodules from the Challenger bank (Plate XXV) in the possession of the Museum were dredged, as already stated, from a depth of about twenty-eight fathoms. The nodules are roughly spherical, with pitted and irregular surfaces. When collected, they were covered with living hydrozoa, other animal forms and algae. The

*Corals and Coral Islands, p. 187.

†Ibid.

‡Challenger Report: Narrative: Vol. I, facing p. 149.

§Voyage of the Challenger: The Atlantic, Vol. I, p. 333.

nodules are of a light cream color, with membranous patches of red and brown dried organic matter, (*Meloboesia*) which continues to produce the characteristic pungent odor of drying marine vegetation. From the weights and dimensions of 56 individuals, the writer has calculated the average size and shape. It is a rounded body, like a slightly crushed sphere, 9.9 centimeters long, 8.7 centimeters wide, and 7.6 centimeters thick. Its weight is 340 grams. The variation of size in the nodules at hand is considerable, the maximum diameters of the 56 individuals lying between 6.8 and 14 centimeters, and the minimum diameters between 5.7 and 11.2 centimeters. The corresponding weights are 118 and 940 grams. Between these limits the sizes and weights of the nodules are distributed with a fair degree of uniformity. While the individual nodules frequently depart far from a true spherical form, they appear on casual inspection to do so in all possible directions, and with no tendency toward any other definite shape than the sphere. When the dimensions of all the specimens are tabulated, however, it appears at once that the majority of the forms are such that the three perpendicular axes or diameters are unequal, and the length of the intermediate is an arithmetical mean between the longest and the shortest diameter. The average nodule, as described above, also has this form. Few of the specimens depart far from these proportions. Many, however, while maintaining their ratios between major, median, and minor axes do depart materially from the form of the spheroid of the same axes. One is in the form of a cone with a large, shallow depression in its base, well to one side of its axis. (Plate XXVI, Fig. 6.) Others have slight flattenings and concavities which are suggestive. Frequently, on the flatter sides of the nodule there will be slight depressions a little to one side of the centre. These forms dimly but persistently suggest half-obliterated forms of familiar gastropod shells. (Plate XXVI.)

The specific gravity of a specimen weighing 540 grams was found to be 2.30.*

The surface of the nodule (Plate XXV) is always of an irregularly rough or warty appearance. It is composed entirely of the skeletons of calcareous encrusting organisms which are chiefly corals, bryozoa and algae. In places the surface is covered with cylindrical branching forms, (*Madracis ?*) which may attain a height of 8 mm. and a diameter for individual cylinders of perhaps 2 mm. These forms were all dead when the specimens were collected, and are in all instances

* See p. 50 for cause of low results.

thickly covered, and partially obliterated by other incrustations. Other portions are covered with somewhat smaller club-shaped branching forms of bryozoa. The entire surfaces of all the specimens are covered with films of encrusting bryozoa, and of a nullipore allied to *Meloboesia* of which many were living when the nodules were collected. The surfaces show also a multitude of forms of other calcareous organisms, including curved worm tubes, fan-like forms, etc., of occasional occurrence. The specimens collected in 1873 by the Challenger were covered with living *Madracis*, which appear in the present specimens to have been replaced for the most part by nullipora and by bryozoa of encrusting rather than branching forms. The larger branching corals, etc., are confined to one-half of the surface, the other half being fairly smooth, and coated only with the smoother encrusting forms. This smooth half probably is the part embedded in the calcareous ooze from which the nodules were dredged. To some specimens are attached completely encrusted shells of sizes up to 45 millimeters. (Plate XXVI, Fig. 4.) The nodules are penetrated frequently by syphon tubes of a Pholas-like shell. These shells were all dead when collected and filled with calcareous sand. Some of the boring mussels are also represented by long-dead shells. There are also numerous serpula-like calcareous tubes penetrating the nodules in every direction. The calcite of the surface is of a friable, chalky, and earthy character, giving no indications of macroscopic crystallization. For purpose of study several specimens were sawn through the centre with a hacksaw. These sections (Plate XXVII) exhibit a chalky, cellular limestone, becoming more solid and denser toward the centre. The cells possess no regularity in form, size, or distribution. Some of the openings are sections of the syphons of *Pholas* or some allied form, of worm tubes and of pelecypod shells; more are merely irregular cavities in the limestone. Towards the centre the cells are smaller, with thicker walls, and toward the surface they are larger, with thinner walls. Upon examination from a distance, the cells have a distinctly concentric arrangement, which disappears upon close examination, except near the surface. Close to the surface, and for a distance inward of six or eight millimeters, the material is in the form of concentric, irregularly waved sheets of calcite, which touch and coalesce in spots enclosing elongated, empty cells lying approximately parallel with the surface. Upon the outside of the nodules there are, in places, thin encrusting bryozoa and algae, which arch away from the nodule in a similar manner. This type of cellular structure dies out

gradually toward the center by a thickening of the walls and a shortening of the cells to approximately equidimensional forms.

The calcite of the body of the nodule is continuous with that of the encrusting forms. There are certain exceptions to this, however. A nodule (Plate XXVI, Fig. 2, and Plate XXVII, Fig. 2) of a shape suggesting an enclosed shell, and about ten centimeters in diameter, when opened disclosed the very light cellular calcite to a thickness of ten to fifteen millimeters, and enclosing an annular core of denser cream-colored rock with a line of demarcation perfectly sharp. This hard material has the shape of a curved loop three millimeters thick, inside of which the cellular material again occurs. It appears to be a section through the shell of a large gastropod. Other sections of specimens display the same character. Nearly all the nodules which were opened contained shells of *Pholas*, or of some allied form. Some specimens of the boring mussels were found, as well. The Pholas-like shells had been dead for some time, and were filled with calcite sand, but the syphon tubes penetrated in every instance either quite to the surface or to within one millimeter of it. Small gastropods completely enclosed and the calcareous tubes of worms are of frequent occurrence.

Such are the nodules from the Challenger Bank. The twenty-eight specimens collected October 13, 1905, from the neighboring Argus Bank are of the same general character, but differ in some respects. They are smaller, and much more irregular in outline, as well as darker colored from the presence of the calcareous algae in larger numbers. They came from a depth of from 28 to 30 fathoms. They vary in diameter from three to eight centimeters, and in weight from 5 to 212 grams. Some of the nodules have the spheroidal form of those from the Challenger Bank, but many have no regularity of shape whatever. Some of them are simply shapeless intergrowths of branching coralline forms, and others appear to be encrustations upon flat shells of various shapes and sizes. The variety in form and size of the specimens from the Argus Bank is well demonstrated by the specimens forming the bottom row of Plate XXV.

A chemical analysis of the substance of a nodule seeming desirable, the inner part of an average specimen of about eight centimeters diameter from the Challenger Bank was taken for the purpose. After about one centimeter had been removed from the outside by chipping, the remaining portion was pulverized to pass a 40-mesh sieve and quartered down to convenient bulk for analysis. The analysis by the author gave the following result:

ANALYSIS OF THE CENTRE OF A NODULE FROM THE CHALLENGER BANK.

CaO	49.66
CO_2	42.92
MgO	2.38
Na_2O	0.34
MnO	0.05
FeO	0.12
Al_2O_3	0.58
SiO_2	0.11
SO_3	0.55
P_2O_5	0.02
Cl	0.37
Loss in ignition*	2.93
	100.03
Less $O = Cl_2$	0.08
	99.95
This corresponds to:	
Calcium carbonate	88.61
Magnesium carbonate	4.98
Ferrous carbonate	0.21
Manganese carbonate	0.08
Miscellaneous,	6.07
	99.95

A magnesia determination was also made upon about two grams of the extreme outer portion of the nodule. 5.12% of magnesia was found, corresponding with 10.70% of carbonate of magnesia. Thus it appears that the exterior of the nodule is more magnesian than the interior.

Inasmuch as the nodules occur isolated on a small bank in the midst of the Atlantic, away from any possibility of impregnation or alteration by waters flowing from pre-existing mineral veins, the presence or absence of minute proportions of the heavy metals is of importance as it bears directly upon the much disputed question of the origin of ore deposits by lateral secretion or ascension. The isolation of the material removes wholly the serious doubt present in most determinations of this character as to whether any metals found may not have originated in mineral veins and later impregnated the surrounding rock. Consequently a search for traces of copper and lead in thirty-seven grams of the nodule material was carried out with great care. There was not a trace of either metal present.

* Less CO_2. Chiefly organic matter and some water. The organic matter makes itself very evident upon igniting the specimen, both by its odor and by blackening.

The magnesian character of so recently formed a limestone of organic origin is somewhat unexpected; even though analyses of reef rock, coral limestone, and coquina invariably show magnesia in similar quantity. The composition of these nodules is essentially that of the Bahama reefs and of other limestones of comparatively recent organic origin.* There are ancient crystalline marbles (e.g. Vermont) which are shown by analysis to have a similar constitution as regards magnesia.

While the source of the magnesia is undoubtedly the magnesian salts in sea water, the *modus operandi* of the transfer from the sea salt to the nodule appears doubtful. There are three possible methods: 1. Formation of the nodules by direct chemical precipitation of the two carbonates; 2. Metasomatic replacement of calcium by magnesium; 3. Secretion of magnesium carbonate with the lime by organisms. The present tendency of geological belief is towards the replacement hypothesis, although there are yet those who believe the older dolomites are direct chemical precipitates. The application of the theory of replacement of lime by magnesia to the present case meets serious objections.

Experimental studies of the replacement of calcium by magnesium in carbonates indicate that under certain abnormal conditions of pressure and temperature such replacements readily occur.† Also a co-precipitation of carbonates of lime and magnesia may be produced under conditions of concentration of the mother liquor which cause it to differ widely from sea water in character. On the other hand, experiments by Bischof,‡ and others have indicated that under normal conditions either such replacement does not occur or takes place so slowly that an experiment of several years' duration yields no perceptible result. So eminent an authority as Mendeléef, however, states that such replacement can occur and will proceed until a condition of equilibrium dependent upon concentration and temperature is attained.§ Such an origin of dolomitic limestones necessarily postulates that they are formed under two sets of widely variant conditions, under one of which the equilibrium is reached at from one to ten per cent magnesium carbonate, and under the other the equilibrium is reached when the magnesium carbonate in the dolomite attains a proportion not greatly below 45.65%, which corresponds to the double salt $MgCO_3.CaCO_3$. Limestones with magnesian content

* U. S. G. S. Bull. 228.

† Fouque et Levy: Synthese des Mineraux, p. 204.

‡ Bischof: Chemical and Physical Geology, vol. III, p. 167.

§ Mendeléeff: Principles of Chemistry, vol. I, ch. 14, footnote 11.

between these limits are of very unusual occurrence, as are carbonate rocks with magnesia much in excess of that in dolomite. Experiments by various chemists and experimental geologists have amply demonstrated that a co-precipitation of magnesia and lime carbonates under normal conditions of concentration, pressure, etc., is impossible. The depth of 28 fathoms, however, corresponds to a pressure of 100 pounds to the square inch, more or less, and under this pressure and at ordinary temperatures experiments have not been carried out.

These considerations are not intended to prove that dolomites and magnesian limestones are never formed by metasomatic processes or by direct precipitation. The evidences of metasomatic origin for some dolomitic limestones which have been summarized by Van Hise* are convincing. It is, however, evident from the above considerations that the conditions under which the Bermuda nodules grew are not such as favor either of these processes of dolomite formation. Inasmuch as the nodules are evidently organic in origin, direct secretion of magnesia by the organisms concerned seems a reasonable hypothesis, especially as such an action would be to the advantage of the organism by rendering its skeleton more insoluble. As some brachiopods and all vertebrates secrete phosphates, and some sponges, diatoms, etc., silica, there seems to be no *a priori* reason why corals, etc., should not secrete carbonate of magnesia together with carbonate of lime. There appears to be an impression which is very wide spread that all such calcareous skeletons are extremely pure carbonate of lime, but a cursory examination of available literature discloses no grounds for such a belief. Dana, Geikie and Prestwich† quoting Dölter and Hörnes' work upon the dolomites of the Tyrols, note that some organically deposited limestone is slightly magnesian at the time of formation. Many writers refer briefly to the work of Forchhammer discussed in the following pages, but either minimize the importance of his results or fail to see their significance.

To determine whether calcareous organisms ever become magnesian enough to account for the character of these nodules magnesia was determined by the author in the Museum laboratory for twelve skeletons of calcareous organisms of various types. With the results of this work are tabulated twenty-one determinations by other analysts. The determinations as given in the table are of the specimens as prepared for exhibition. These naturally contain dried

* U. S. G. S. Mon. XLVII, p. 802.

† Dana: Manual of Geology, p. 134; Geikie: Textbook of Geology, p. 321; Prestwich: Geol. Vol. I, p. 113.

organic matter in considerable quantities, so that the ratio of magnesia to lime carbonates in the skeletons alone is higher than indicated by the percentages obtained for the dried specimens, which latter percentages are the ones in the accompanying table.

MAGNESIUM CARBONATE CONTENT OF THE SKELETONS OF VARIOUS MARINE CALCAREOUS ORGANISMS.

Analyses by the author in Roman type; those by other analysts in italics.

No.	Mus. No.		$MgCO_3$ %
		ALCYONOID CORALS.	
1	377	Eunicea tourneforti, Bahamas,	2.78
2	381	Plexaurella dichotoma, Bahamas,	2.11
3	——	*Isis hippuris,**	6.362
4	——	*Corallium nobile,**	2.132
5	——	Corallium rubrum, Mediterranean,†	9.32
6	314	Tubipora musica, Singapore,	3.83
		ZOANTHOID CORALS.	
7	126	Coeloria daedolea, Abyssinia,	0.35
8	——	*Astraea cellulosa,**	0.542
9	——	*Siderastraea sp., Bermuda,‡*	0.42
		BRYOZOA.	
10	1041	Flustra foliacea, California,	1.23
11	——	*Eschara foliacea,**	0.146
12	1052	Garapholas sp.,	3.99
13	——	Bryozoan? Bermuda,	5.35
14	1057	Lithoramnion racemus, Bahamas,	0.65
15	——	*Myriazoon truncatum,**	0.455
16	——	*Heteropora abrotanoides,**	0.352
17	——	*Frondipora reticulata,**	0.596
		PELECYPODA.	
18	2879	Teredo gigantea, Indian Ocean,	0.00
19	——	*Ostrea sp.,§*	0.3
20	——	*Modiola papuana,**	0.705
21	——	*Pinna nigra, Red Sea,**	1.000
		GASTROPODA.	
22	G1331	Vermetus sp., Bermuda,‖	0.35

* Analysis by J. G. Forchhammer: 1849. Bidrag til Dolomitens Dannelshistorie: Oversigt over det Kongelige Danske Videnskab. 1849, pp. 83–96.

† Polished material from a necklace.

‡ Analysis by L. G. Eakins; Bull. U. S. G. S., No. 228, p. 308.

§ Analysis by Sharples? Dana: Manual of Geology, p. 72.

‖ The incrustation of specimen shown in Plate XXVI, Fig. 5.

23	——	*Tritonium pompilius*,*	0.486
24	——	*Cerithium telescopicum*,*	0.189
		BRACHIOPODA.	
25	——	*Lingula ovalis*,†	3.59
26	——	*Terebratula psittacea*,*	0.452
		VERMES.	
27	——	*Serpula sp. Mediterranean*,*	7.644
28	——	*Serpula triqueta. North Sea*,*	4.455
29	——	*Serpula filograna*,*	1.349
		CRINOIDEA.	
30	P6877	Metacrinus rundus, Japan,‡	11.72
		CEPHALOPODA.	
31	——	*Nautilus pompilius*,*	0 118
32	——	*Ossa sepiae [Sepia sp.]*,*	0.401
		ALGAE.	
33	——	*Lithothamnium nodosum*, §	5.5

It may also be noted that Sharples when in 1871 he determined the phosphate in seven zoanthoid corals observed that traces of magnesia were present in all, but made no quantitative determinations. A. Damour¶ also found small quantities of magnesia in many millepores.

From the above results it appears that the algae, crinoidea, vermes and alcyonaria secrete relatively magnesian skeletons, while the zoantharia, pelecypoda, gastropoda and cephalopoda secrete skeletons which are only slightly magnesian.

These analyses thus explain why the inner portion of the nodule analysed by the author, (p. 45) is less magnesian than the outer part. This nodule like many of the others was formed in and around a large gastropod. The more highly magnesian corals, serpulae and algae of which the nodule is composed are in the central part diluted by the less magnesian gastropod material. It is probable that the magnesium of the outer part is also somewhat increased by that re-solution of the skeletal material which is always taking place.

If under present conditions corals, etc., secrete skeletons which may contain over ten per cent carbonate of magnesia, may they not, under palaeozoic conditions, when, as is usually conceded, the sea

†Analysis by T. Sterry Hunt: Logan's Geology of Canada, 1863. The ash analyzed was 61 per cent of the whole shell and gave 2.88 per cent Mg O, whence the equivalent Mg CO_3 for the entire shell has been calculated.

‡Cirri and pinnulate arms from an alcoholic specimen. The organic matter is 22 per cent.

§Analysis by Gumbel; Geikie: Textbook of Geology, p. 482.

Sharples: Am. J. Sci., III ser., vol. I, p. 169.

¶Dana: Manual of Geology, p. 72.

water was very different in composition and possibly far more corrosive than at present, have protected themselves by secreting relatively insoluble dolomite skeletons?

From their composition and structure it is very evident that these objects are accretions and not rolled fragments of preexisting rock. Therefore they have no bearing upon questions relating to subsidence. From the continuity between the living covering of the nodules and the calcite of the interior, as well as from the detection under the microscope of organic structure in this calcite it becomes certain that the accretions are of organic growth. They are not, however, individual animals, for organisms of many kinds are intermingled in them. They owe their existence to a sequence of events substantially as follows: The surface of the bank was covered with a soft calcareous ooze upon which coralline organisms could get no foothold. Upon this ooze certain gastropods and other shells were able to live. Also it is possible that the shells of dead animals may be transported to the bank by the current of the Gulf Stream. The Challenger secured living starfish there and other forms of li e. Such gastropod, echinoid and other shells provided the firm anchorage denied by the ooze for encrusting calcareous organisms of many kinds. These, growing generation over generation, have built up the nodules. If the growth of the nodules is more rapid than the deposition of the ooze, then they will eventually coalesce and form a surface from which a coral reef may grow upwards toward the surface.

THE SPECIFIC GRAVITY OF CLAYSTONES

When it was attempted to compare the specific gravities of the concretions herein described with the densities of other concretions, it was found that apparently such densities had never been determined. Therefore after the specific gravities of the specimens strictly comparable with those under consideration had been secured, the work was continued by the determination and comparison of the densities of fifty-four claystones from eight localities.

The specific gravities were obtained in the usual manner by weighing in water after immersion to complete saturation. Claystones are permeable to water and absorb it in large quantities, but, after the first few minutes, very slowly. A constant weight in water is seldom attained with less than twelve to twenty-four hours immersion. Frequently the weight is appreciably constant only after treatment for several days.

Claystones cannot be boiled to hasten saturation as they disintegrate to a serious extent. For specimens of this character the use of the air pump is of but little value. This very slow permeability of partially saturated claystones is a necessary consequence of the peculiar mesh-like structure already described by Emerson.* The rate of absorption becomes less as the outer parts become saturated until it is so small that increase in weight of the specimen under treatment is masked or imperceptible for periods as great as 24 hours. The last air of the interior is trapped and can be removed only by solution in the water. This solution is greatly impeded by the slight mobility of water confined in the capillary spaces so that the dissolved air can be removed by only slow diffusion unaided by convection currents in the water. The density obtained for claystones is therefore less than the true density by a quantity which is greater the thicker the specimen. It is undesirable, however, in order to avoid this presumably small and regular error, to introduce the error due to solution of cement and consequent disintegration of the surface which would arise from too prolonged immersion of the specimen. This latter error which is found to be very large and also very irregular has to be guarded against most carefully. This disintegration from the surface of clay stones in water is so great with specimens from some regions that all attempts to ascertain their density proved futile. Where an abundance of material may be sacrificed in the work, pycnometer methods may possibly yield results free from these errors but the experience of the author has been that little dependence can be placed upon pycnometer determinations made upon such small quantities of material as could be sacrificed for this purpose. Hence no such determinations were made. The specific gravities of the claystones examined are tabulated on page

When the forms of the specimens were compared with their densities an apparent relationship between the density and relative thickness appeared. To properly compare these features a numerical value for the rotundity or flatness of the specimen is absolutely necessary. As a suitable expression for the variation of form in this respect the term modulus of rotundity is proposed. The diameter of that circle which has an area equal to the horizontal projection of the concretion is calculated or measured. This divided by the extreme thickness gives the modulus of rotundity, a number which is greater for the thinner forms and which becomes unity for the

*U. S. Geol. Survey, Monograph XXIX, p. 717.

sphere. This number is of a very convenient magnitude, varying from 1 to 16.4 for the forms in the collections. This modulus is the reciprocal of the coefficient of rotundity.

TABLE OF SPECIFIC GRAVITY AND MODULUS OF ROTUNDITY OF CLAY-STONES.

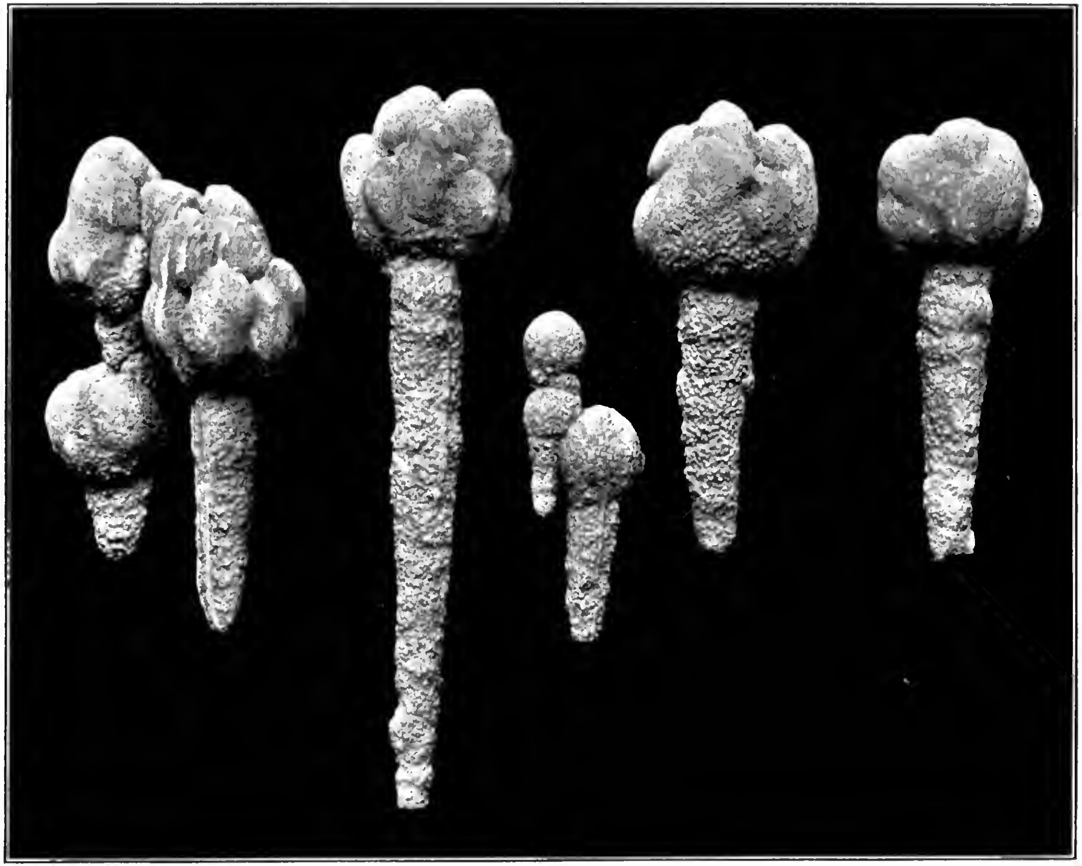
No.	S.G.	M.R.	Locality.	Mus. No. G
1	2.77	11.6	Riga, Vermont.	41-1
2	2.76	8.9	"	39-1
3	2.76	8.2	"	66-2
4	2.75	9.8	"	39-2
5	2.75	11.1	"	41-3
6	2.74	11.1	"	72-3
7	2.74	10.6	"	72-1
8	2.74	8.8	"	69
9	2.73	6.3	"	72-2
10	2.71	5.1	"	39-3
11	2.68	3.6	"	37-3
12	2.68	2.6	"	38-1
13	2.67	4.1	"	37-4
14	2.67	2.9	"	69-4
15	2.66	2.0	"	40-1
16	2.66	1.7	"	40-2
17	2.66	1.7	"	69-2
18	2.65	3.3	"	38-2
19	2.65	1.7	"	40-2
20	2.64	1.9	"	69-3
21	2.63	3.5	"	37-2
22	2.63	3.0	"	37-1
23	2.77	7.3	Connecticut River.	805-6
24	2.73	8.1	"	805-8
25	2.73	4.6	"	76-2
26	2.71	5.6	"	752-2
27	2.71	1.8	"	805-7
28	2.70	5.9	"	70-2
29	2.70	3.0	"	70-1
30	2.69	4.5	"	55-2
31	2.69	3.9	"	75-1
32	2.69	2.0	"	805-2
33	2.69	1.5	"	805-4
34	2.69	1.5	"	805-5

35	2.68	3.4	Connecticut River	805–1
36	2.68	3.3	"	55–1
37	2.68	3.2	"	76–3
38	2.68	2.9	"	805–3
39	2.68	2.7	"	75–2
40	2.67	5.3	"	76–1
41	2.67	3.4	"	70–3
42	2.67	3.4	"	805–9
43	2.70	2.0	Hartford, Connecticut.	751
44	2.76	3.0	Deerfield, Massachusetts.	753–2
45	2.73	1.6	" "	753–1
46	2.93	16.4	South Hadley, Massachusetts.	73
47	2.71	8.1	Charleston, New Hampshire.	755–1
48	2.67	2.2	" "	755–3
49	2.66	3.9	" "	755–2
50	2.78	7.8	Cumberland, Maine.	757–1
51	2.77	2.4	" "	757–2
52	2.76	2.3	" "	757–3
53	2.68	5.4	Broad Cove, Maine.	756–2
54	2.68	3.4	" "	756–1
55	2.63	1.4	" "	756–3

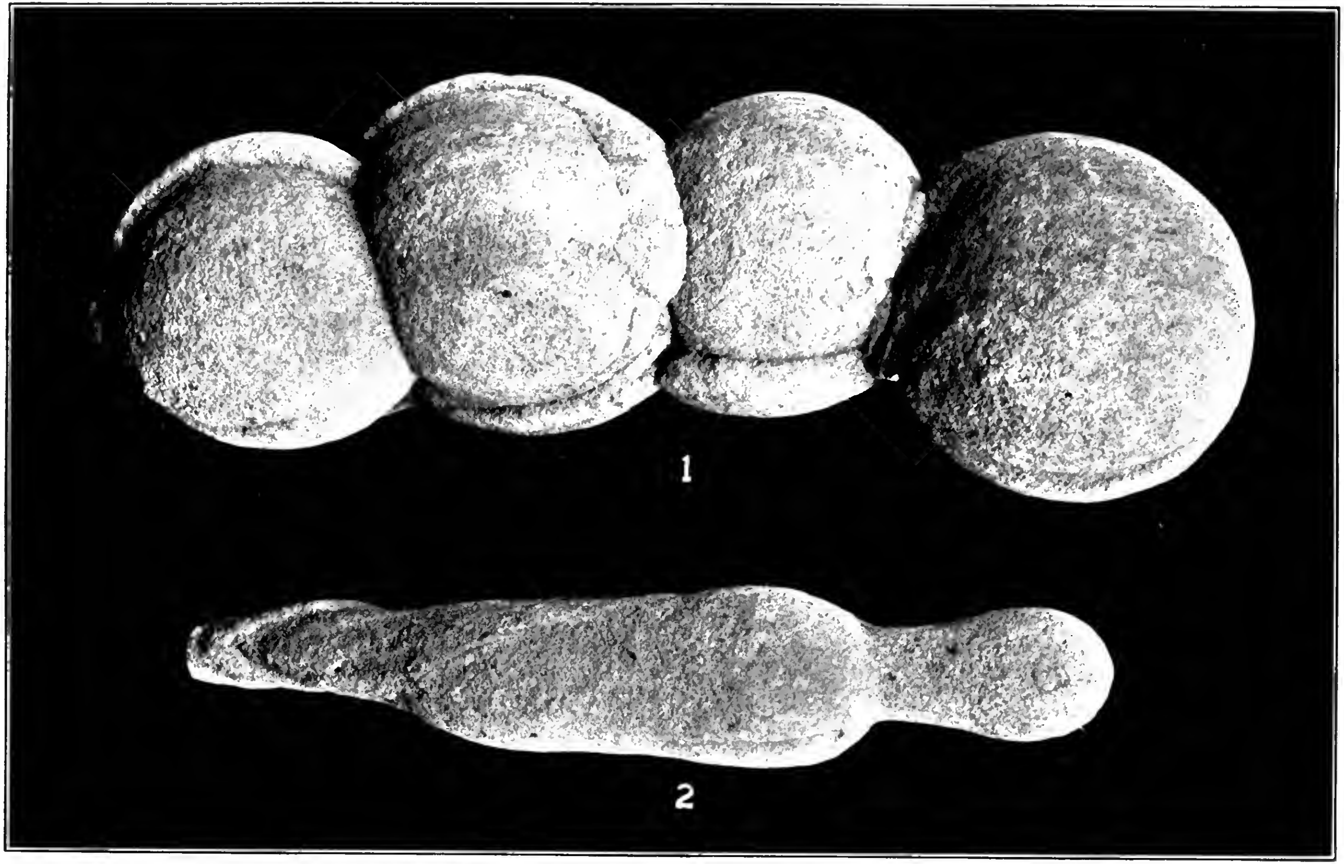
Of all the specimens examined those from Riga, Vermont, are available in the largest numbers and vary most in thickness. Their forms are extremely simple varying from nearly spherical to thin, wafer-like disks with but few irregular shapes. They are therefore favorable specimens for study. Of the twenty-two from this region examined, the twelve with specific gravity below 2.70 have a modulus below 5. The ten specimens with specific gravity above 2.70 have a modulus above 5. Thus the modulus of rotundity seems to increase in a general way with the density. It is probable that the increase in density with increased thinness is only apparent and is really due to those defects inherent in the methods of determination which have already been stated.

Claystones, as impure concretions, are subject to many purely fortuitous variations in composition. It is of importance to note that almost any such variations from normal composition will give a specimen of greater specific gravity than the typical claystone. The glacial clays in which claystones commonly occur are rock flours of varied composition. As a general rule they consist essentially of floured quartz, kaolin and kaolinized feldspars and calcite. Such

clays have a true specific gravity between 2.62 and 2.65. This clay persists unchanged throughout the substance of all claystones formed in it. Any pebble or other foreign substance in the clay is enclosed by and made a part of any claystone that forms in the proper position. With the exception of quartz any pebble likely to be encountered in concretion-bearing beds is considerably heavier than the surrounding clay. Bits of shell, frequently encountered in claystones from some localities, render the concretion in which they occur heavier than normal. Rock flour clays may, and frequently do, contain pulverized minerals of many species, practically all of which are heavier than the normal quartz and kaolin. Spots and seams stained with iron oxides, segregations of magnetic iron sand, pulverized hornblende, etc., are not at all uncommon. The cement of a claystone is, so far as known, essentially calcium carbonate. Usually it is somewhat magnesian and occasionally ferriferous. In either case the specific gravity of the concretion is increased. Fortuitous variations in composition and structure therefore commonly increase the specific gravity. It is astonishing that in bodies apparently subject io purely fortuitous changes so many and so great, this change of density with form should not be entirely masked. That it is not so masked, suggests that there are only narrow limits of structure and quality of clay and cement within which the formation of these concretions is possible.

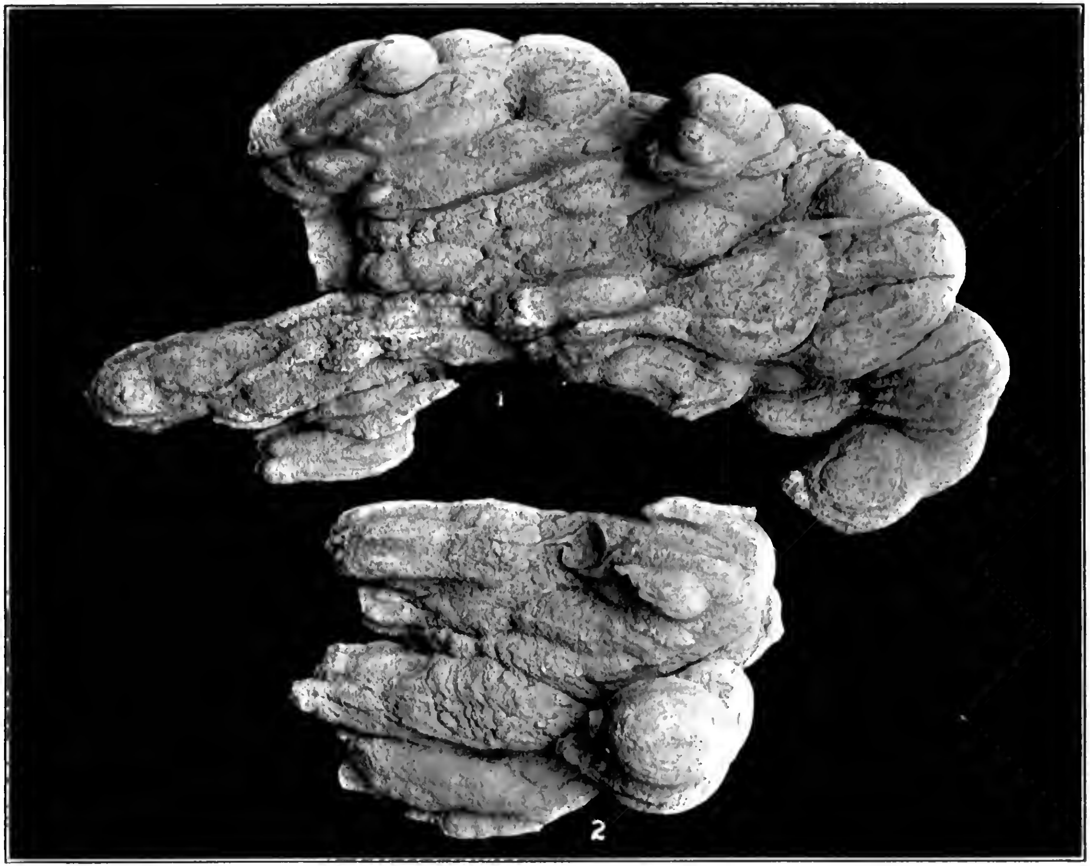


Sand-Calcite Concretions Salton, California, $\times \frac{1}{3}$



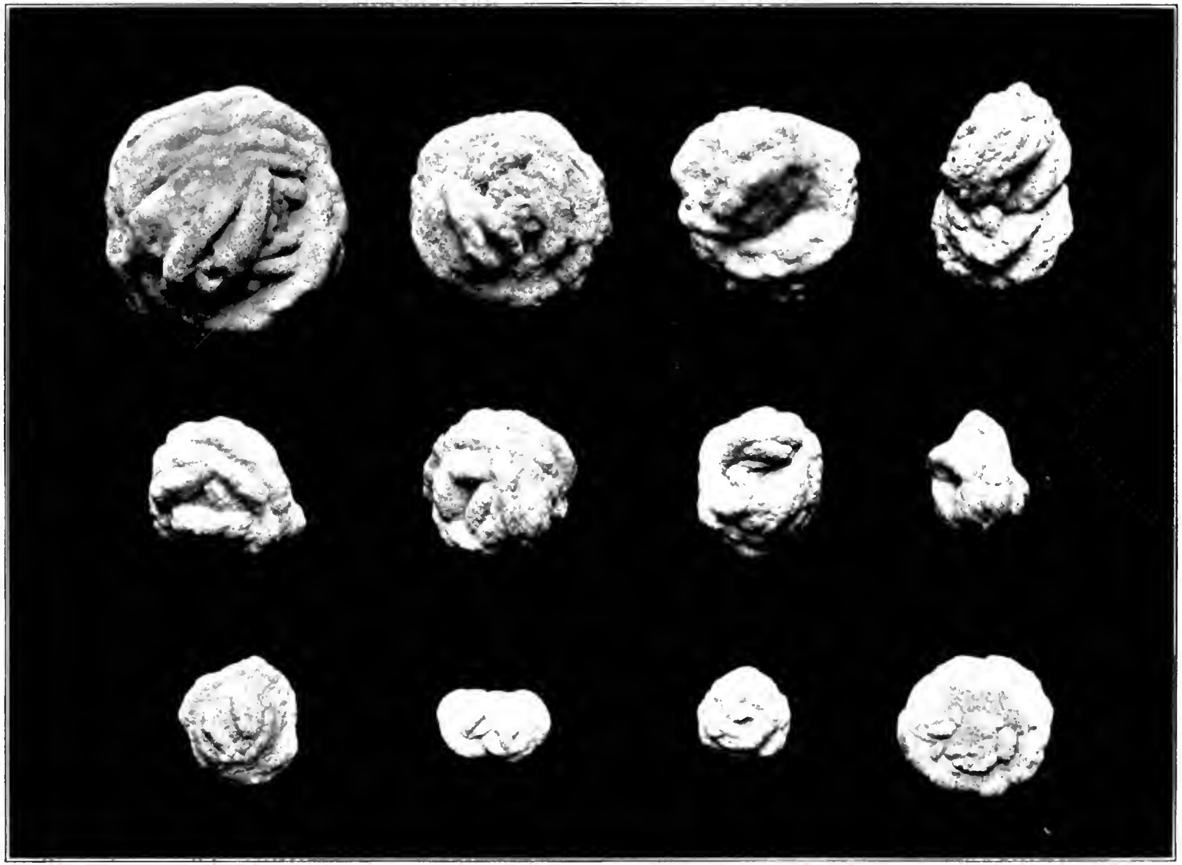
SAND-CALCITE CONCRETIONS, $\times \frac{1}{3}$

FIG. 1. Clermont, France.
FIG. 2. Saratoga Springs, New York.

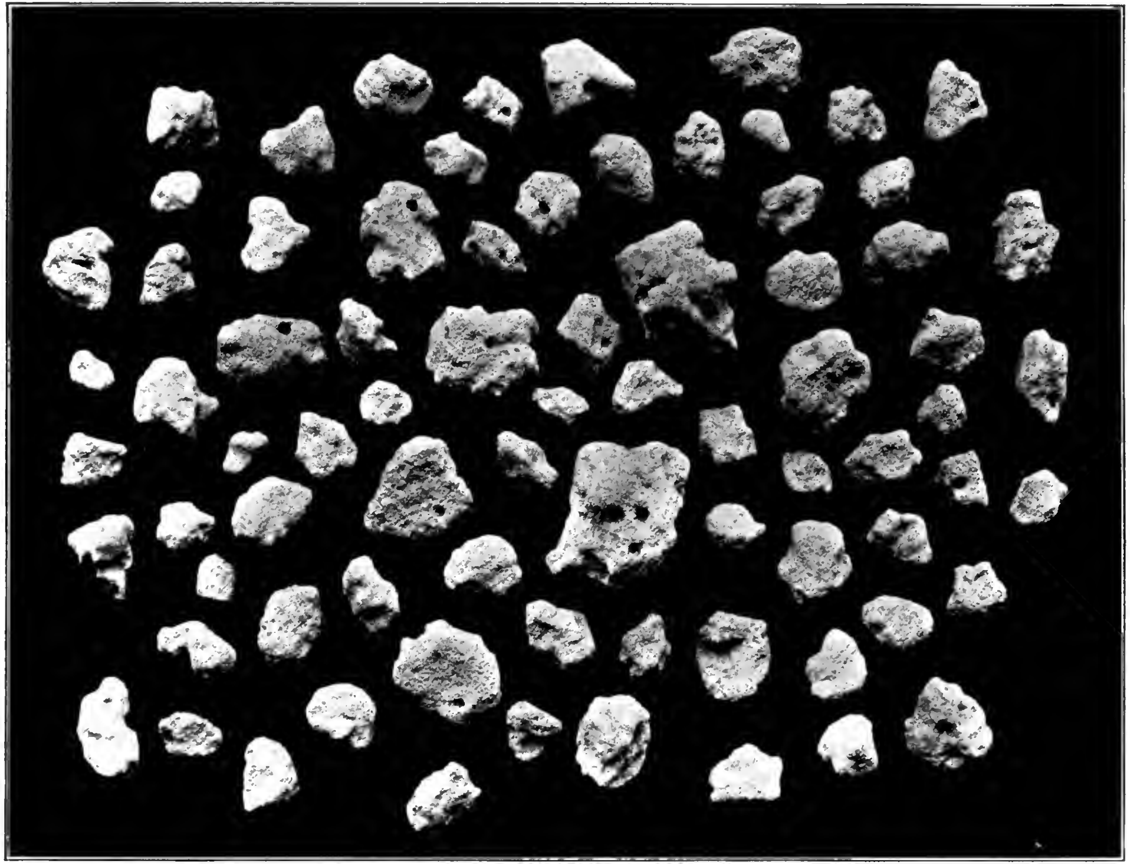


SAND-CALCITE CONCRETIONS, SARATOGA SPRINGS, NEW YORK, $\times \frac{1}{3}$

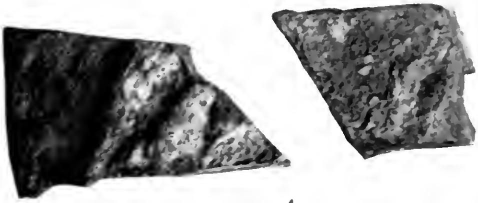
FIG. 1. Congruence of individual concretions.
FIG. 2. With a typical ovoid individual.



SAND-BARITE CRYSTALS, OKLAHOMA, × ½



LIMONITE-SAND CONCRETIONS, SPRING LAKE, MICHIGAN. × 1



1

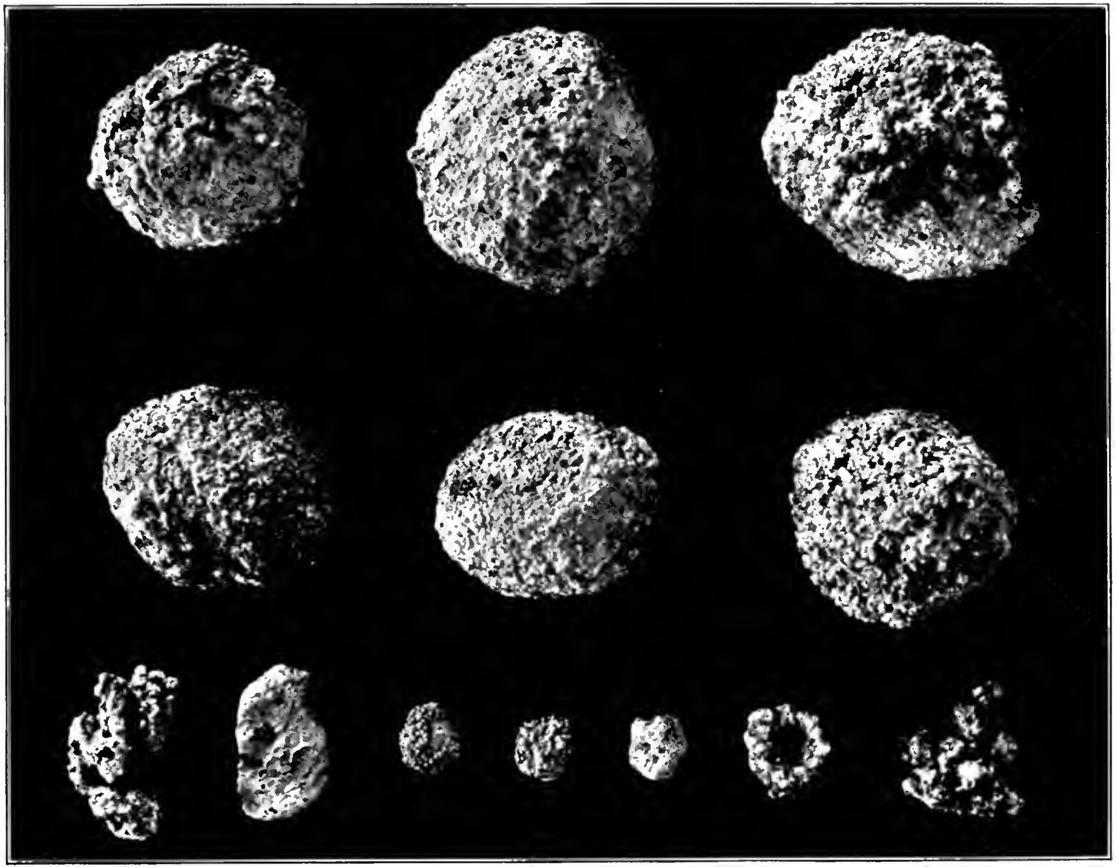
2

3

4

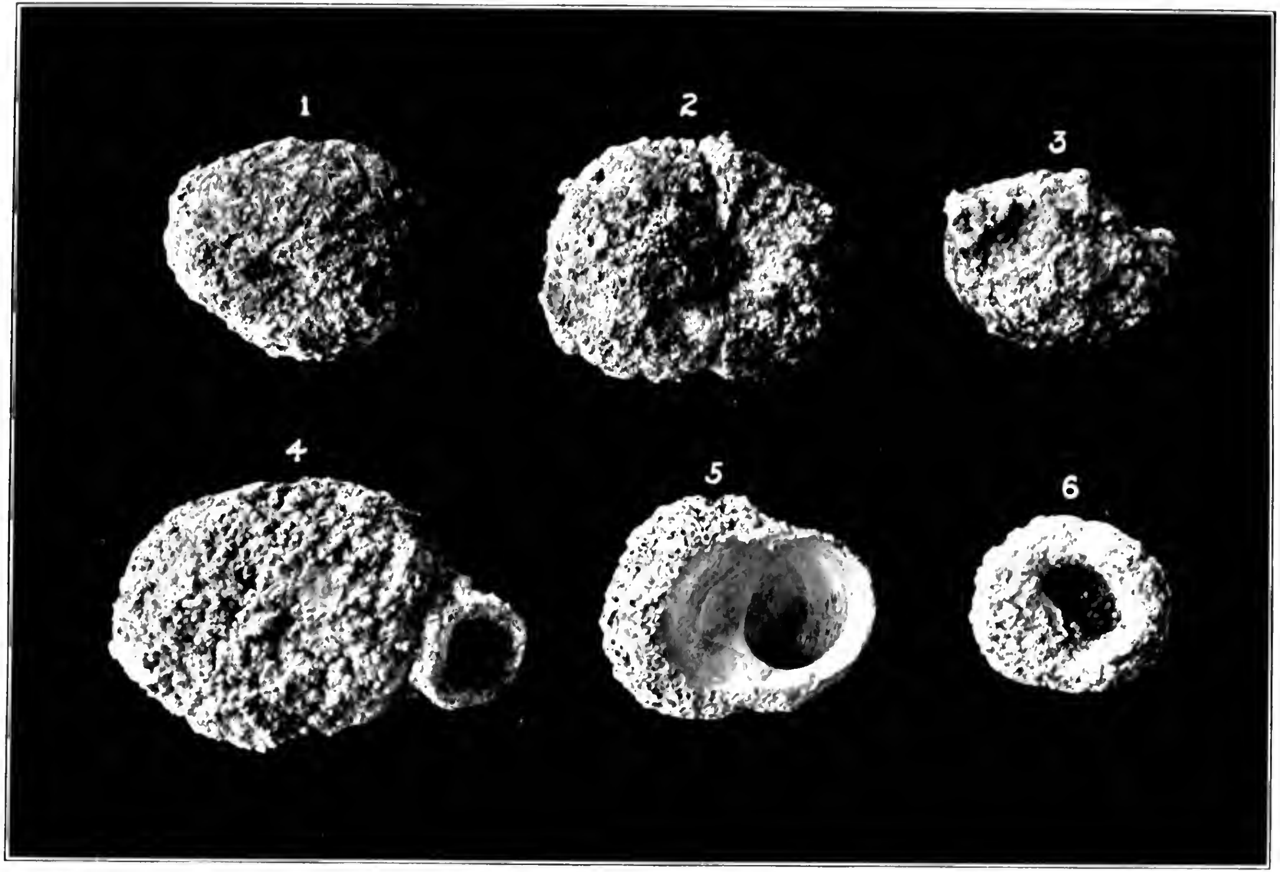
LIMONITE GEODES, × $\frac{5}{8}$

FIG. 1. Two adjacent geodes, Kentucky.
FIG. 2. Section of twin geode, Kentucky.
FIG. 3. Section of geode, Muskogee, Indian Territory.
FIG. 4. Limonite geode, Muskogee, Indian Territory.

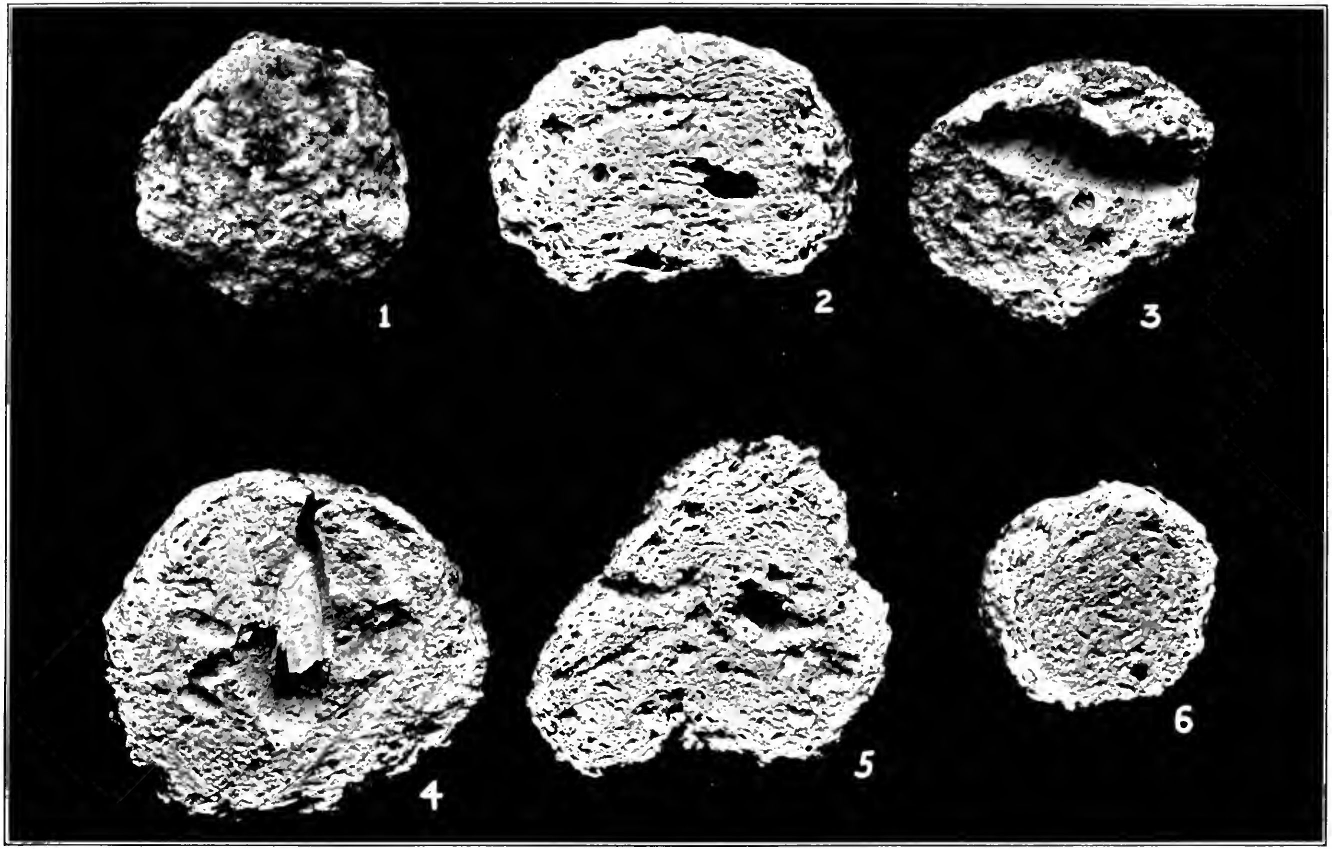


NODULES FROM THE CHALLENGER AND ARGUS BANKS, $\times \frac{2}{7}$

The upper rows are from the Challenger Bank.
The lower row is from the Argus Bank.



NODULES FROM THE CHALLENGER BANK, × $\frac{1}{3}$



SECTIONS OF NODULES FROM THE CHALLENGER BANK, × ½